Armed Forces College of Medicine

AFCM

Acid-Base Balance

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INTENDED LEARNING OBJECTIVES (ILO)

By the end of this lecture the student will be able to:

1. List the principal buffers in blood and importance of each .
2. Define acidosis and alkalosis , give the normal mean and the range of pH in blood that are compatible with health.
3. Describe the changes in blood chemistry that occur in metabolic acidosis and alkalosis and the respiratory and renal compensations for these conditions .
4. Describe the changes in blood chemistry that occur in respiratory acidosis and alkalosis and the renal correction of

Lecture Plan

1. Part 1 (5 min) Introduction
2. Part 2 (35 min) Main lecture
3. Part 3 (5 min) Summary
4. Lecture Quiz (5 min)

Introduction

- Free H^+ concentration in ECF is very low. It averages about 0.00004 mmol/L (40 nmol), compared to the plasma Na^+ concentration of 140 mmol/L.

- The H^+ concentration should be kept constant so as to keep the normal activity of many enzymes.

- H^+ concentration is kept constant by a balance between gain and output.

Sources of H^+

1- Ingested: some free H^+ is ingested in food we eat.

2- *Metabolism of food:*

a) Metabolism of carbohydrates:

- The degradation of carbohydrates can generate as mush as 12.000 - 20.000 mmol of H2CO3 (volatile acid) each day.

$$H_2O + CO_2 \xrightarrow{CA} H_2CO_3^+ \rightarrow H^+ + HCO_3^-$$

Sources of H^+

b) ***Metabolism of proteins:*** About 40 - 60 mmol of fixed acids may be produced from protein metabolism each day.

c) ***Lactic acid*** *produced in the muscle* when inadequate supplies of O_2 are delivered to muscle as in severe muscular exercise.

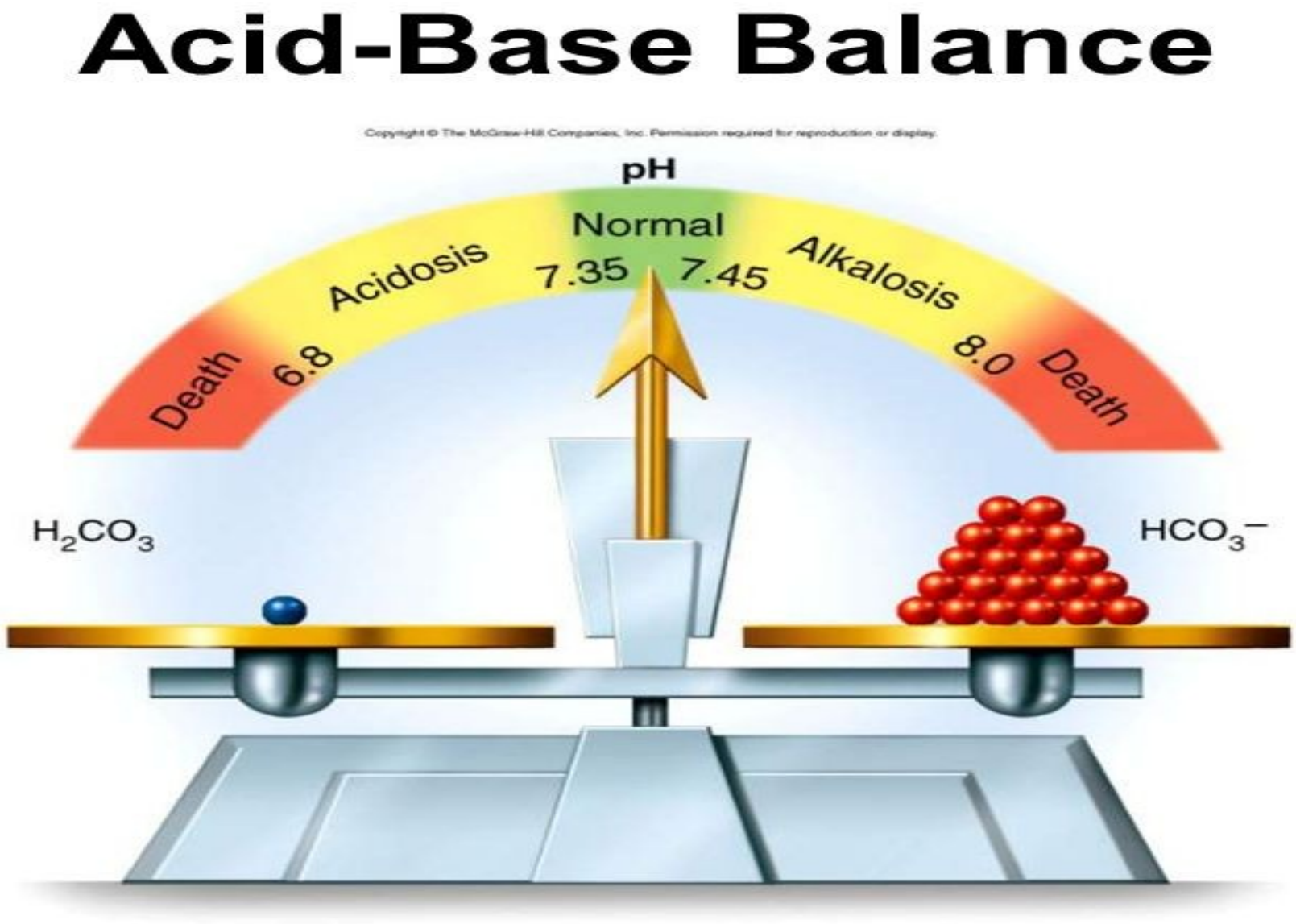
d) Ketoacids (aceto-acetic and β-hydroxy buteric acid) are produced when there is increased metabolism of fat with lack of insulin in diabetes mellitus.

Sources of H^+

p H

- The H^+ concentration is expressed by pH which is the minus log to base 10 of H^+ concentration.
- pH = $- \text{Log}_{10} [H^+]$
- pH of ECF = $- \text{Log}_{10}$ 0.00004 = 7.4
- It's slightly alkaline.
- Life is compatible within narrow range of pH; between 7.35-7.45
- Death occurs if the pH falls below 6.8 or rises above 8.0

Acid - Base disturbances



Regulation of Acid - Base Balance

There are three major systems involved in the regulation of H^+ concentration (pH):

1) *The buffer systems:* minimize the change in free H^+ concentration.

2) *The respiratory system:* eliminate's H^+ derived from CO_2.

3) *The kidneys:* excrete the fixed acids and restores the HCO3 buffer.

Buffer Systems

- There are many buffers in the body.
- The combination of all buffers determines the free H^+ concentration.
- **Relation between pH and the ratio of concentration of the buffer members.**
- It is expressed by: **Henderson-Hasselbalch equation.**

Henderson-Hasselbalch Equation

pH of a buffer = pK + log $_{10}$ (salt)/(acid)

- *Where:*

  pK: dissociation constant.

  When Henderson-Hasselbalch equation is applied to the bicarbonate-carbonic acid buffer:

  $[HCO_3^-]$ = 24 mmol/L

  $[H_2CO_3]$ = PCO_2 x solubility co-efficient.

  = 40 x 0.03

  pK = 6.1

∴pH of arterial blood = 6.1 + Log_{10}

= 6.1 + Log_{10}

= 6.1 + log

Role of buffers in regulation of acid-base balance

- Buffers act immediately to trap H^+ temporarily until respiratory and renal mechanisms act.

- They only minimize the change in H^+ concentration.

Types of buffer systems

1. Bicarbonate buffer system:

H_2CO_3/ $BHCO_3$ (B= Na^+ or K^+)

2. Phosphate buffer system:

BH_2PO_4 / B_2HPO_4

3. Protein buffer system:

a) Plasma proteins.

b) Hemoglobin.

c) Tissue proteins.

Bicarbonate Buffer

Physiological Importance of Bicarbonate Buffer:

1. Its components can be physiologically controlled:

- [HCO_3^-] is regulated by the kidneys.
- [H_2CO_3] is regulated by the respiratory system.
- Therefore, it is very effective buffer.

2. Its pK 6.1 is far from the pH of the blood.

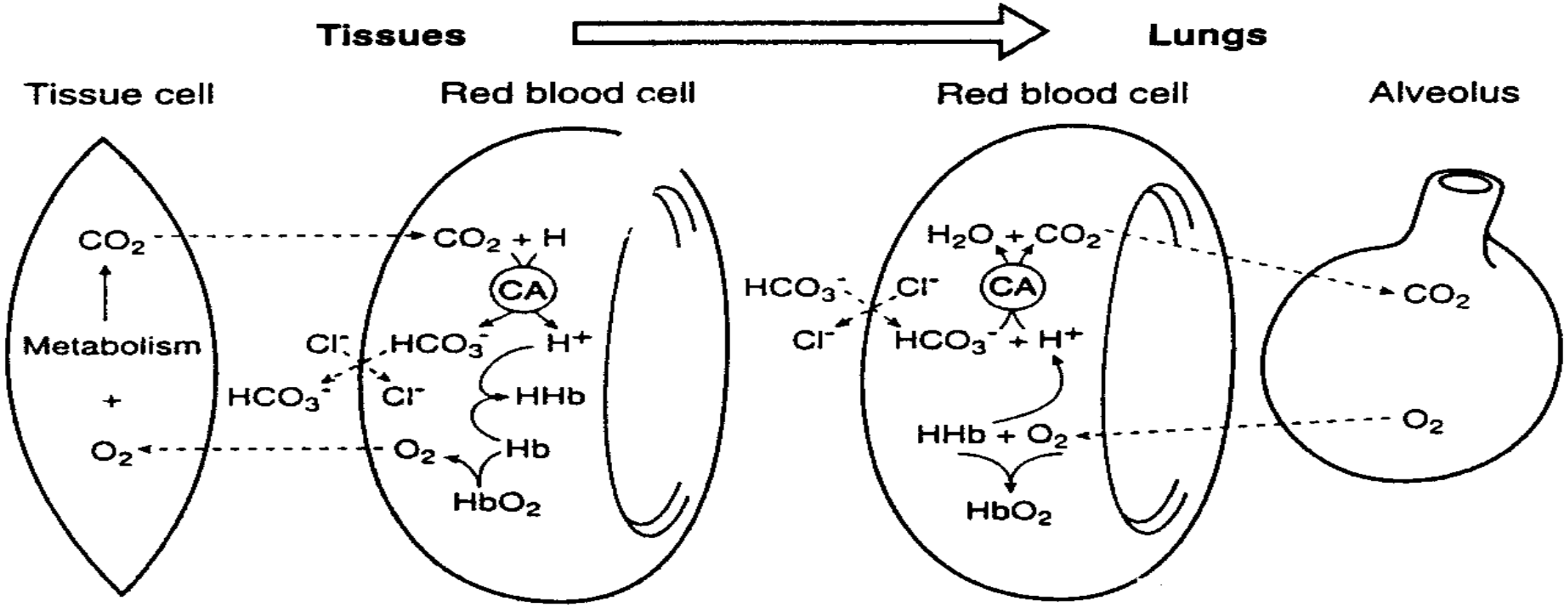
3. Its amount is not large 24 mmol/L.

4. Changes in pH that result from an alteration in either HCO_3^- concentration or PCO_2 can be corrected by changing the other variable to preserve the buffer rat

Haemoglobin Buffer

Physiological Importance:

1. It plays an important role in buffering CO_2.
2. High buffering capacity: It has 6 times the buffering capacity of all plasma proteins, .



Phosphate Buffer

1) It is not a strong buffer extracellularly as its concentration is low (about 1 mmol/L).

2) It is an important buffer:

   a. Intracellularly, due to its high concentration.

   b. In the tubular fluid particularly in the distal convoluted tubule.

3) Its pK (6.8) is near to that of the plasma pH.

Respiratory Regulation of Body Fluids pH

The respiratory control of pH is done through controlling of the blood PCO_2.

Mechanism of Respiratory Control of pH

1. An increase in H^+ concentration (in metabolic acidosis):

It stimulates the respiratory centers through the peripheral chemoreceptors. Hyperventilation eliminates CO_2 and therefore keeps ratio NaHCO3 I H2CO3 constant with . Final correction is brought about by the kidney.

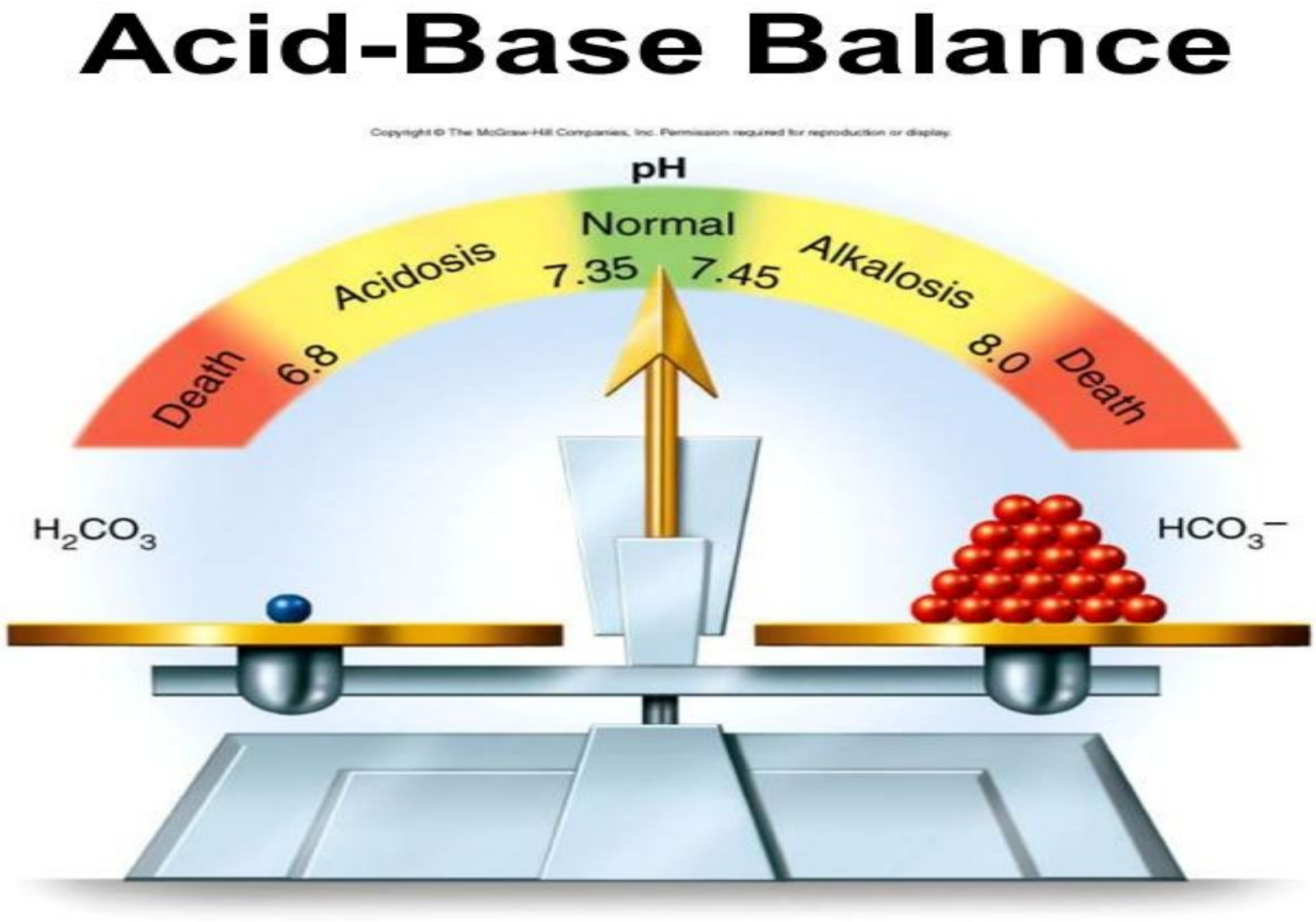
2. A decrease in H^+Concentration below normal (in metabolic alkalosis):

The respiratory centre becomes depressed. CO_2 retention increase H^+ concentration back toward normal.

Renal Control of Acid - Base Balance

The kidneys are capable of bringing pH back toward the normal within 12-24 hours in most cases. The renal control of acid-base balance is the most efficient and most powerful mechanism. (See H^+ secretion and HCO_3^- reabsorption by renal tubule).

Acid - Base disturbances



Types of acid - base disturbances

- Acidosis : Arterial pH is below 7.35.
- Alkalosis: Arterial pH is above 7.45.

From Henderson - Hasselbalch equation: pH depends upon the ratio **HCO_3^- / PCO_2**

pH α kidney/ respiration

Accordingly, the disturbance may be:

- **Respiratory:** The primary change is in PCO_2:
  a) Respiratory acidosis: An increase in PCO_2.
  b) Respiratory alkalosis: A decrease in PCO_2.

- **Metabolic:** The abnormality of pH results from a change in [HCO_3^-]:
  a) Metabolic acidosis: decrease in [HCO_3^-]
  b) Metabolic alkalosis: increase in [HCO_3^-]

Metabolic Acidosis

It is characterized by:

a) Arterial blood pH is less then 7.35.

b) Decreased plasma [HCO_3^-].

Causes:

1. Excess production of fixed acids:

a) Diabetic ketoacidosis: addition of acetoacetate and B-hydroxybutrate to the blood

b) Anaerobic production of lactic acid in shock,severe exercise and anaemia.

c) Aspirin poisoning Salicylic acid.

d) Methanol poisoning formic acid.

Metabolic Acidosis

2. Decreased elimination of fixed acids by the kidney
e.g. renal failure.

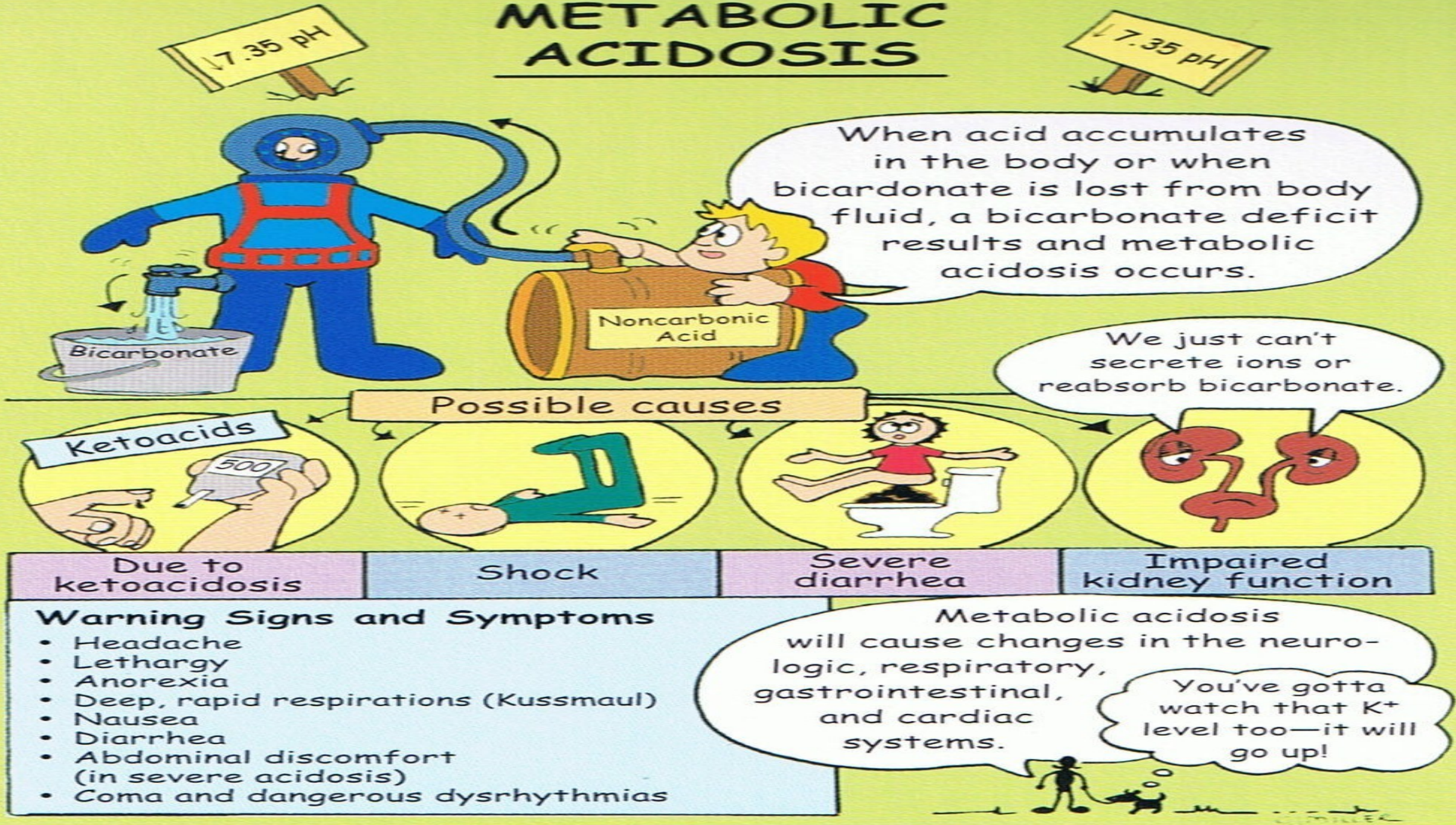
3. Loss of HCO_3^-:

a) Prolonged or severe diarrhea.

b) Pancreatic fistula.

c) Addison's disease.

METABOLIC ACIDOSIS



Respiratory compensation

- Increased H^+ concentration is a very potent stimulus to increase ventilation via the peripheral chemoreceptors. Increased ventilation rapidly lowers arterial PCO_2 and returns [H^+] toward normal.

Renal correction: restoration of the plasma [HCO_3^-] to normal by increasing HCO_3^--generation and ammonia formation by the kidney.

Metabolic Alkalosis

It is characterized by:

1. Rise of arterial plasma pH above 7.45.
2. Increased plasma [HCO_3^-].

Causes:

\An increase in plasma [HCO_3^-] due to:

1) Persistent vomiting:
2) Excess intake of alkali to treat peptic ulcer.
3) Cushing syndrome
4) Conn's syndrome

K^+ leaves the cells in exchange with H^+ → (HCO_3^-) rises

5) Diuretics: except carbonic anhydrase inhibitors.

Respiratory compensation

Respiratory centres are inhibited by decreased [H^+].

Hypoventilation elevates arterial PCO_2.

pH returns toward normal. However, increased PCO_2 is a very potent stimulus to increase ventilation and thus PCO_2 only slightly increases. Thus, the respiratory component for metabolic alkalosis is not nearly so powerful as the respiratory component for metabolic acidosis.

Renal correction:

Decreased HCO_3^- reabsorption by the renal tubule and increased loss of HCO_3^- in urine to lower plasma HCO_3^-.

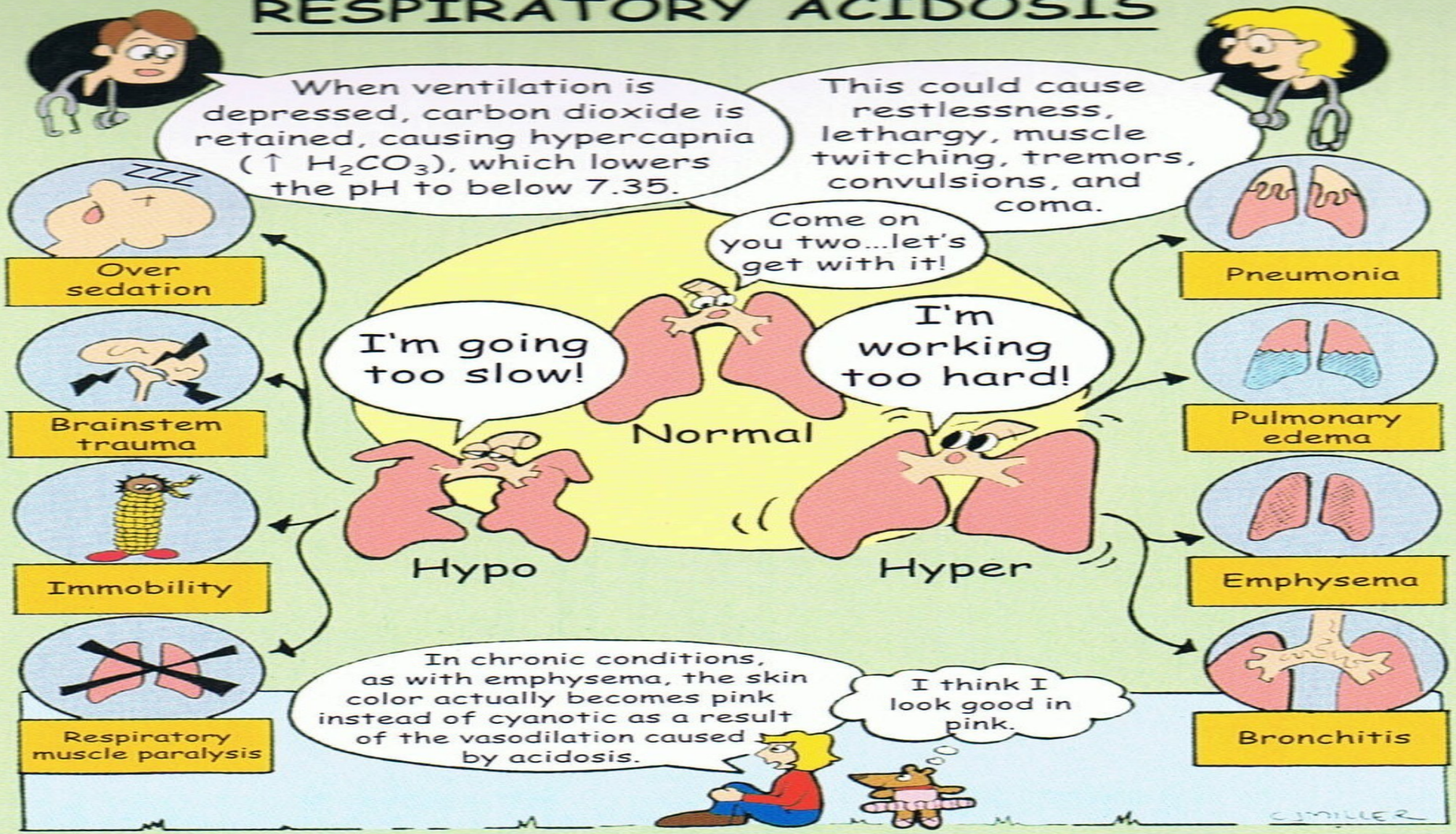
Respiratory acidosis

- It is characterized by: arterial blood pH less than 7.35.
- Increased arterial PCO_2 more than 44 mmHg.
  (HCO_3^-) / PCO_2

Causes:-

1. Depression of the respiratory centre by narcotics or excess sedation.
2. Air way obstruction: emphysema - bronchial asthma - asphyxia.
3. Paralysis of the respiratory muscles.

RESPIRATORY ACIDOSIS



Respiratory Acidosis

Renal Compensation

- Increased the plasma HCO_3^- concentration thus the ratio $(HCO_3^-) / PCO_2$ is constant.

- The increased PCO_2 acts as a stimulus to increase the formation of H^+ and HCO_3^- from $CO_2 + H_2O$ in the renal tubular cells. The renal H^+ is secreted and the new HCO_3^- is returned to the plasma.

Respiratory Alkalosis

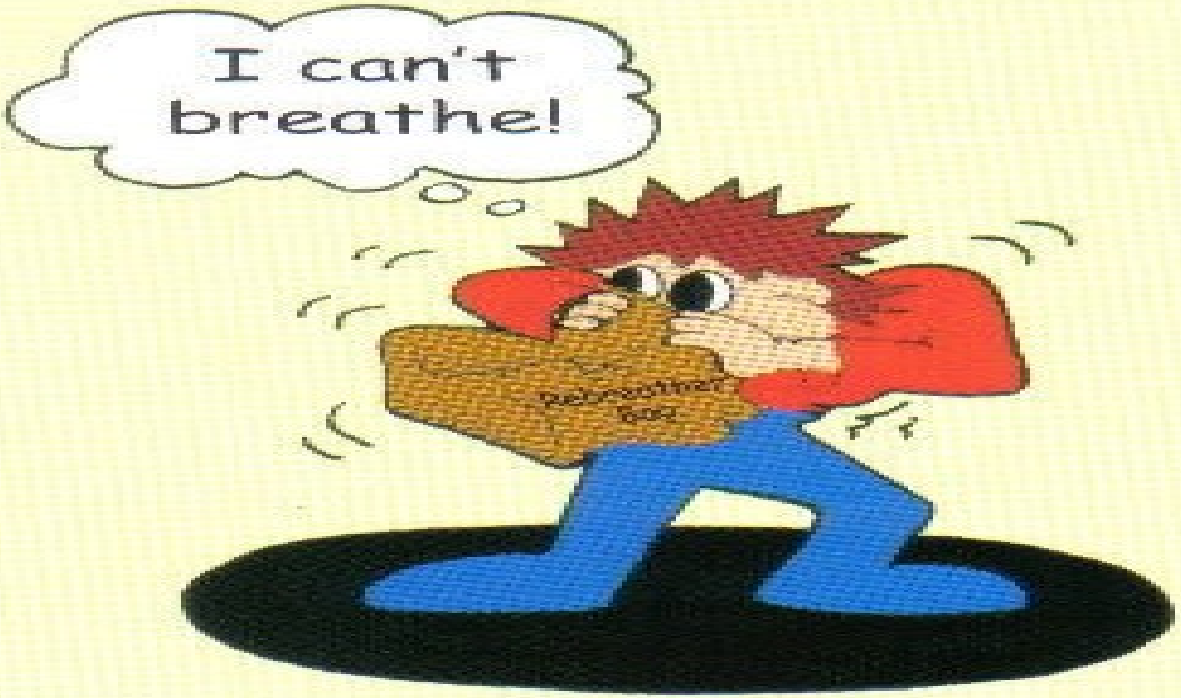
It is characterized by:

1) Arterial blood pH higher than 7.45.
2) Decreased arterial PCO_2

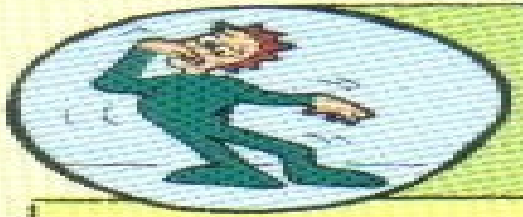
Causes:

1. Respiratory response to high altitudes.
2. Psychological dyspnea and anxiety.
3. Fevers.
4. Early in exercise.

RESPIRATORY ALKALOSIS

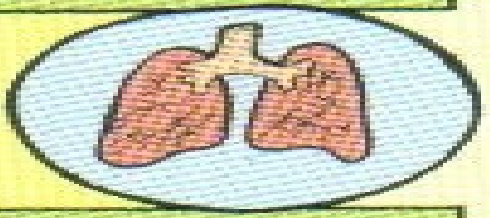


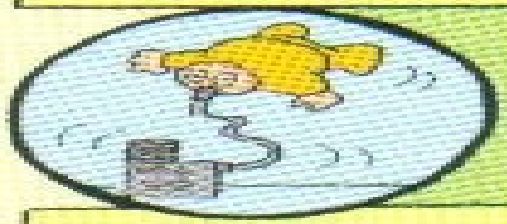
Typical Causes



Hyperventilation with Anxiety

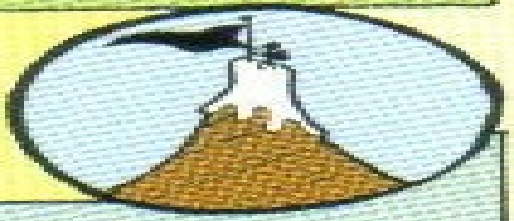
Pulmonary Disease





Ventilator Settings Too High or Too Fast

High Altitudes



Deep and rapid respirations (tachypnea) will cause an ↑ loss of CO_2 and will cause respiratory alkalosis. Check ABGs and serum K and Ca levels. Slow down the respirations, and keep the patient hydrated.

Do I need a rebreather bag when I pant?

Respiratory Alkalosis

Compensation:

The kidneys decrease plasma [HCO_3^-]:

- Decrease reabsorption of the filtered HCO_3^-
- The decreased CO_2 decreases the generation of H^+ and HCO_3^- by the tubular epithelial cells.

ANION GAP

- The total cation charges in the plasma always equal to the total anion charges present .
- However , only major ions are measured when calculating the anion gap .
- The anion gap is due to unmeasured anions.
- Cations are estimated as the plasma concentration of the cation , Na+ . Anions are estimated as the plasma Cl- and HCO3- .

ANION GAP

- Normal Values:
- Na^+ = 140 mEq /L
- Cl- = 108 mEq /L
- HCO3- =24 mEq/ L
- Normal anion gap =5 – 11 m Eq /L
- The negative charges on plasma protein anion account for most of the anion gap . The anion gap is useful in diagnosing the cause of metabolic acidosis . The anion gap will increase in states in which acidosis is accompanied by accumulation of organic anions e.g., diabetic ketoacidosis , lactic acidosis and salicylate poisoning .Anion gap will be normal in metabolic acidosis caused by diarrhea ?

Summary

Acid Base Disorders

Disorder	pH	$[H^+]$	Primary disturbance	Secondary response
Metabolic acidosis	↓	↑	↓ $[HCO_3^-]$	↓ pCO_2
Metabolic alkalosis	↑	↓	↑ $[HCO_3^-]$	↑ pCO_2
Respiratory acidosis	↓	↑	↑ pCO_2	↑ $[HCO_3^-]$
Respiratory alkalosis	↑	↓	↓ pCO_2	↓ $[HCO_3^-]$

lasting for 7 days. Which of the following would be

Lecture Quiz

a)Anion gap
b) Filtered load of HCO3
c) H secretion by distal convoluted tubule
d)Production of ammonia by proximal convoluted tubule
e) Production of new HCO3 by distal convoluted tubule

Question 2 In noncopensated respiratory :
a) The usual cause is chronic hypervetilation
b)The pH may be normal
c) Blood Pco2 will be elevated
d)Blood Pco2 will be low
e) Plasma HCO3 will be high

SUGGESTED TEXTBOOKS

1. Ganong,s Review of Medical Physiology 25th Edition (Textbook Name) from page 713-716.
2. TEXTBOOK OF Medical Physiology 11th EDITION GUYTON and HALL from page 383-400.